eRD16: Forward/Backward Tracking at EIC using MAPS Detectors

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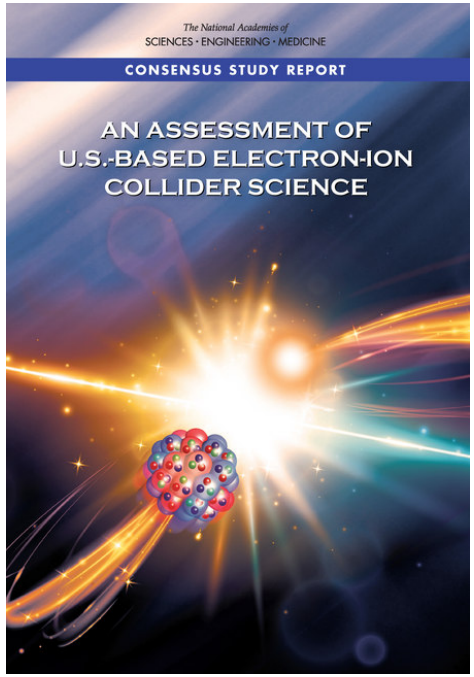
Abstract

This report describes progress in the period between July 2019 and December 2019 on continued conceptual development of tracking stations with silicon-sensors near the collision vertex to detect the scattered electron and produced secondary hadrons at forward and backward angles with respect to the EIC beams. The overall goal is to arrive at an optimized geometrical configuration of disks with thinned-silicon sensors using science-driven specifications as a tracking subsystem that includes conceptual arrangement of services and is well-integrated with tracking subsystems covering the central barrel region. Part of this work is being pursued in collaboration with eRD18, which focuses on mid-rapidity (vertex) tracking and sensor development.

Forward/backward Tracking - Why?



Endorsed science case and, since this past December, CD-0

Four nuclear-physics themes:

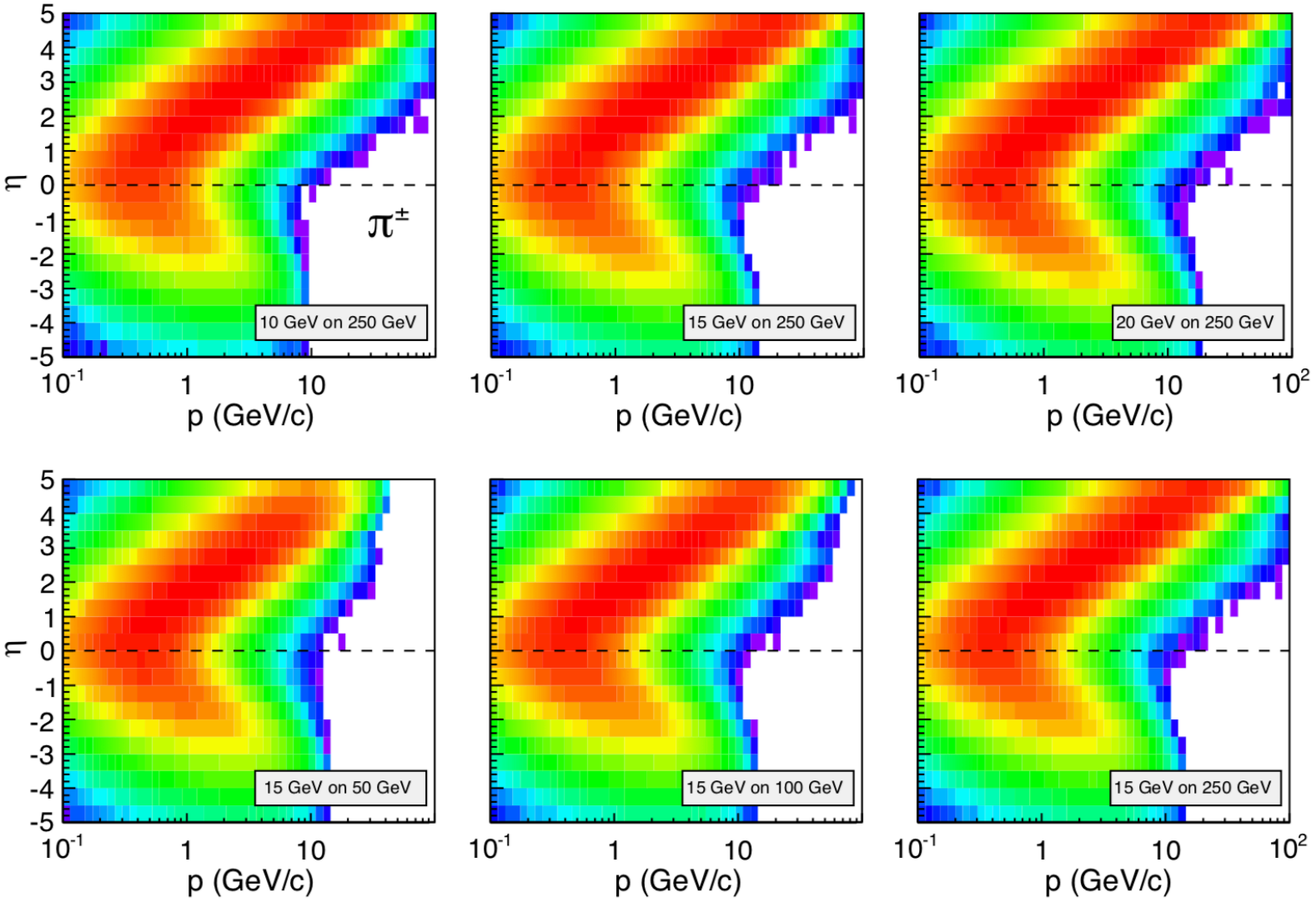
- nucleon spin,
- imaging in nucleon and nuclei,
- gluon-dense matter / saturation,
- hadronization and fragmentation

Most/all measurements require *large* acceptance,

High resolution is a must in the solenoidal fields of current general purpose detector designs,

Traversed material will need to be kept in check, especially in the electron direction.

Forward/backward Tracking - Why?

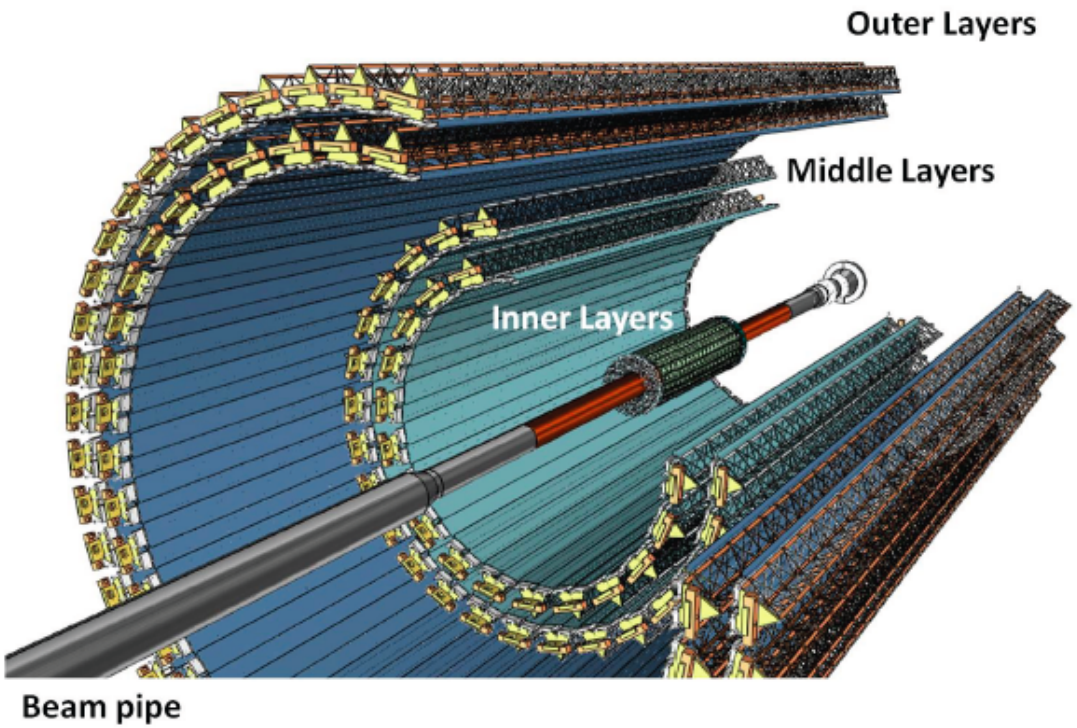


Charged-pions produced in deep-inelastic scattering (c.f. EIC Detector Requirements and R&D handbook, figure 12)

Recent Group Instrumentation Projects

STAR HFT-pixel is complete,

ALICE ITS last LBL-produced staves are at CERN,



- 7 layers
- 10 m^2 of silicon
- Installation in early 2019
- X/X_0 ~ 0.3% (inner layers)
- X/X_0 ~ 0.8% (outer layers)

Makes use of CERN-developed MAPS sensors, ALPIDE:

Dimensions:	15mm x 30mm
Pixel pitch:	28µm x 28µm
Integration time:	approx. 4 µs
Power consumption:	39mW/cm^2

TDR: http://iopscience.iop.org/0954-3899/41/8/087002/

sPHENIX vertex tracker gearing up.

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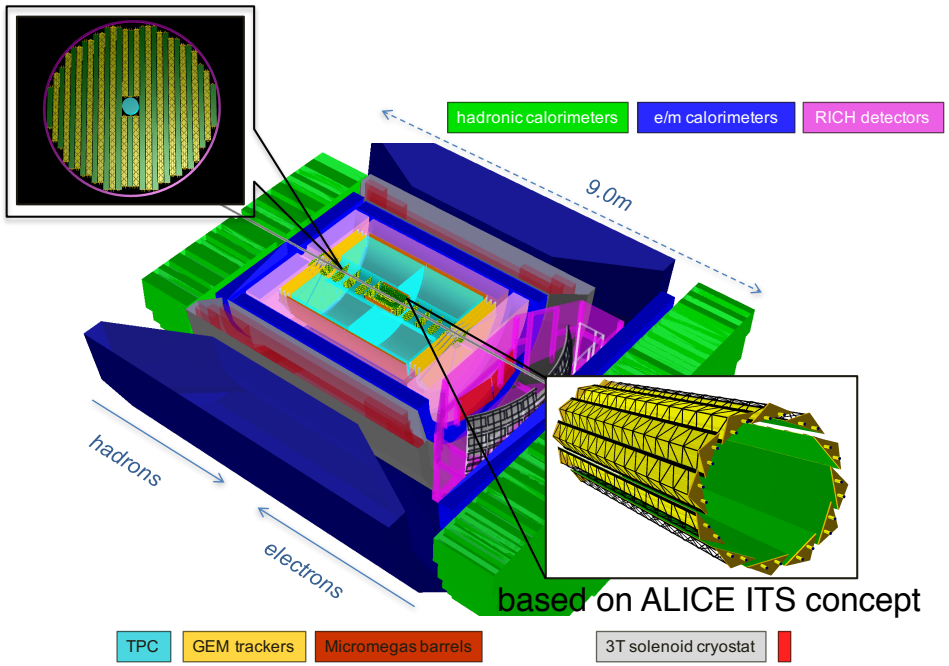
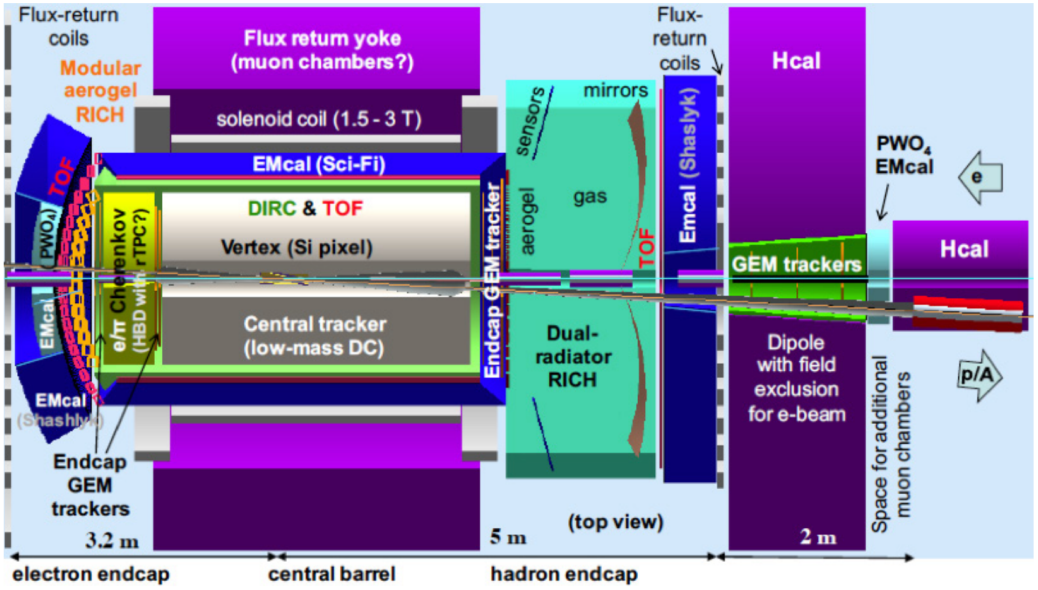
EIC Detector Concepts*



BeAST concept



JLEIC detector concept

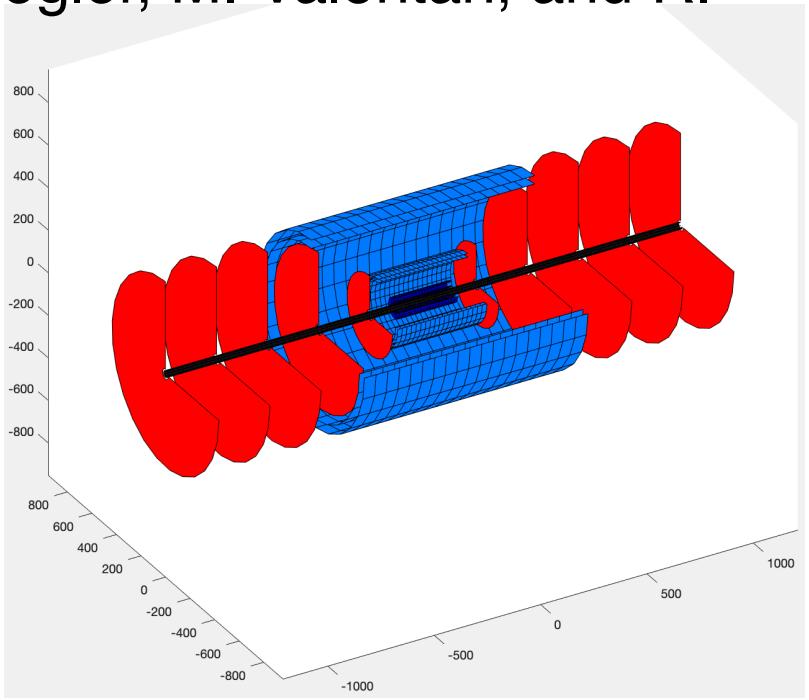
Si-based *inner* tracking and vertex detectors*, covering central and forward regions, for eRHIC as well as JLEIC detector concepts,

EIC needs: large acceptance, low mass, and high resolution.

*Other concepts exist; e.g. J. Repond et al. have put forward an all-Si tracker sPHENIX transition to a day-1 EIC detector.

eRD16 - Simulation Tools

- Charged-particle tracking toolset originally developed for ILC studies by the Vienna group, M. Regler, M. Valentan, and R. Frühwirth (2008):
  - Helix track model,
  - Multiple scattering,
  - Full track reconstruction from digitized hits using a Kalman filter
  - Documented and published*.



Hypothetical all-Si tracker in a 1.5T Solenoidal field.

- Rapid studies of number of layers, disks, geometrical layout, etc.
- Work done mostly with (former) undergraduate students.

* issue identified of (~unphysical) correlation loss between p_T and dip-angle identified in back-propagation dp/p through the beampipe, but not yet corrected - delays documentation.

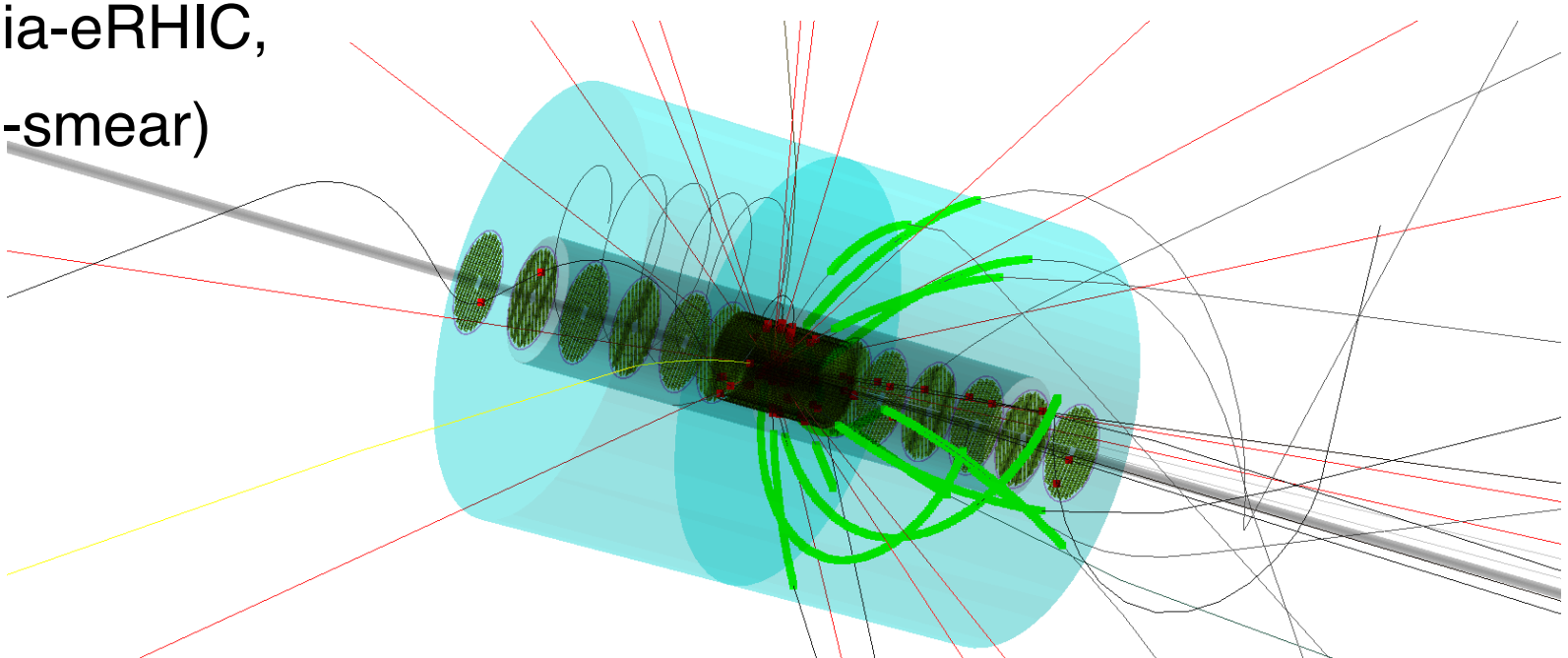
eRD16 - Simulation Tools

- Toolset(s) developed by EIC task-force at BNL;

  EICRoot; GEANT3-based simulations

  Pythia-eRHIC,

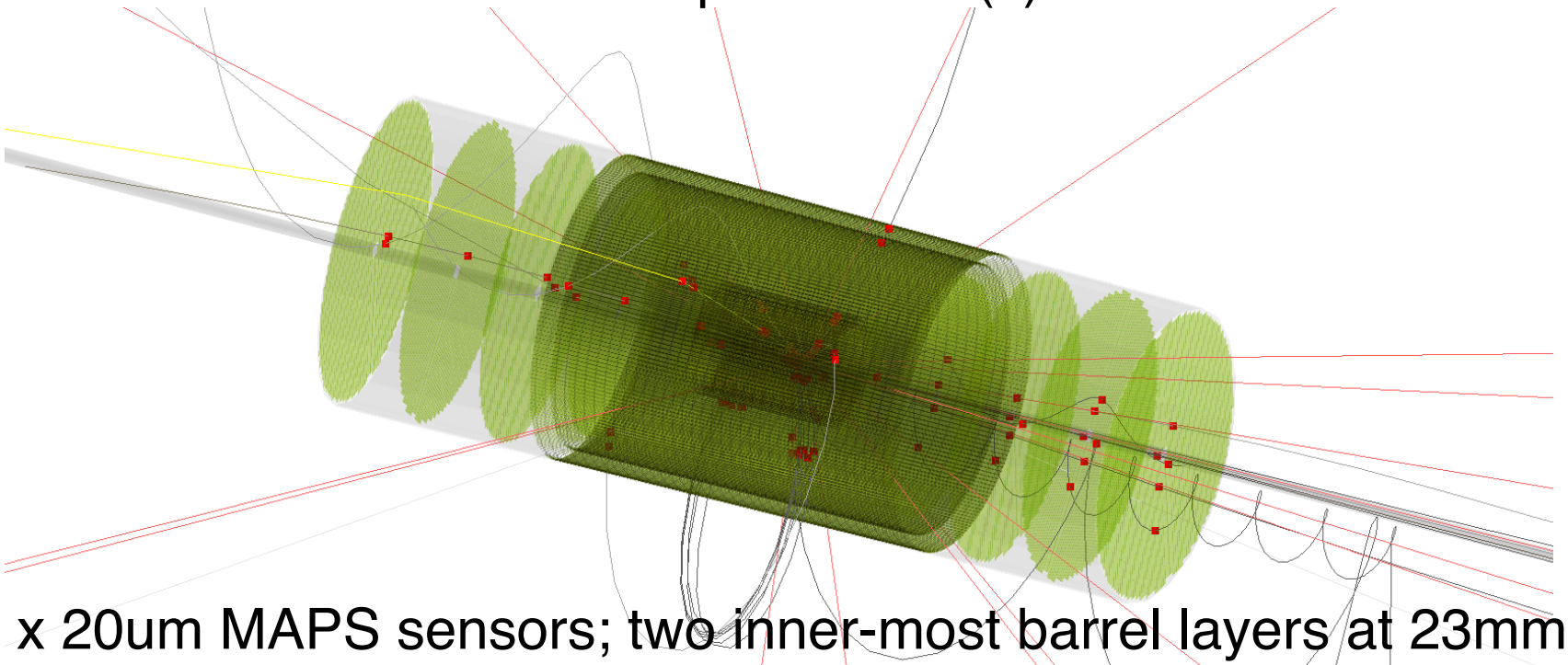
  (EIC-smear)



- Default: BeAST TPC with refined configuration of silicon disks and integration with eRD18 barrel tracker - eRD16 work with Y.S. Lai.
- Toolset for most of what follows and into the near-term future.
- Initial explorations of alternatives, so far mostly Fun4All with UC-Berkeley and UC-consortium colleagues.

eRD16 - Simulation Tools

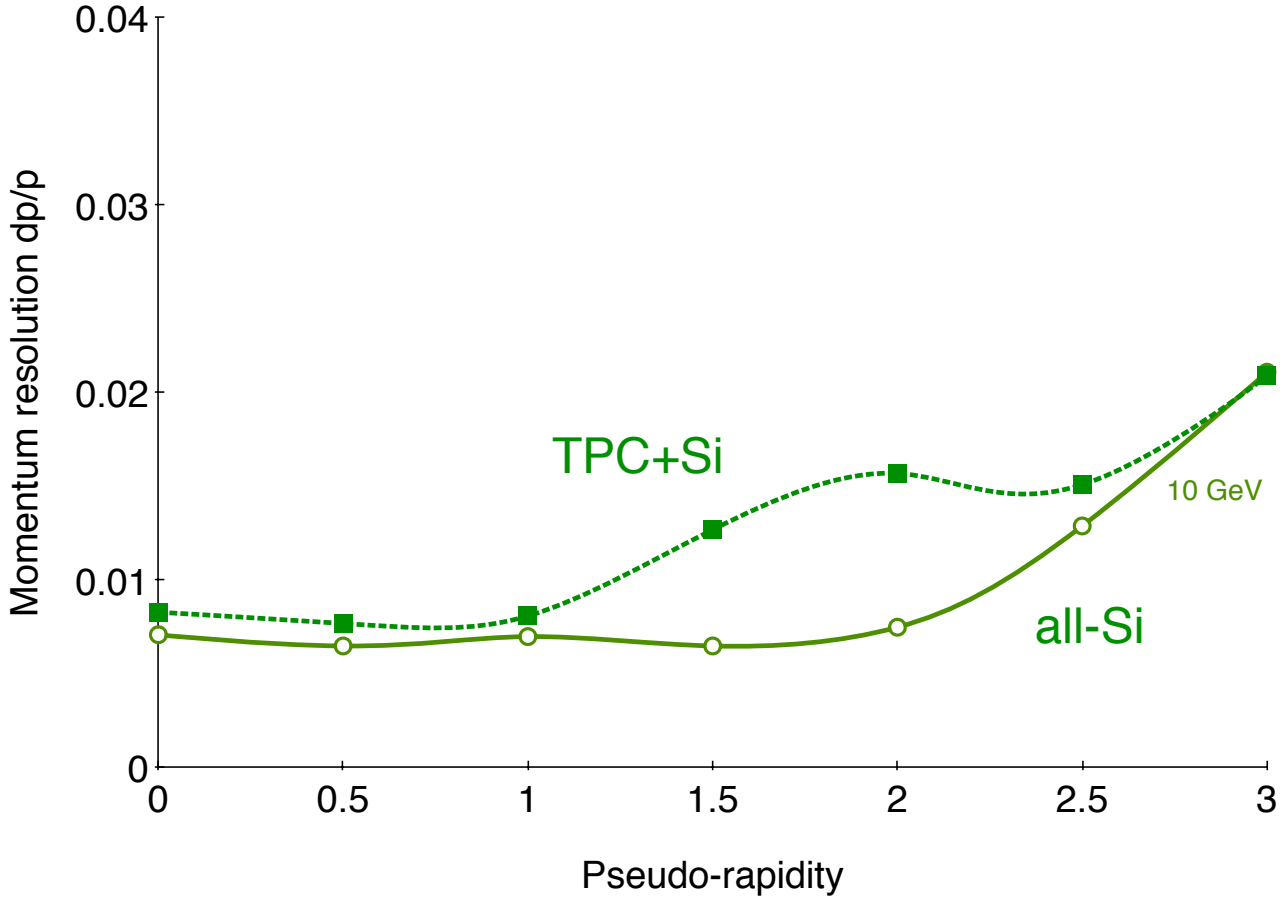
- eRD16 presented initial studies of an all-silicon concept using the BNL-EIC task-force developed toolset(s):



- 20 x 20um MAPS sensors; two inner-most barrel layers at 23mm and 46mm drive vertexing performance, surrounded by barrel layers at 14.0 and 15.7cm, and 39.3 and 43.2 cm, complemented with 5-7 forward and backward disks spanning z ~ 1m.
- p_T (resolution) steps at ~0.4 (0.2) GeV in 3.0 (1.5) T.
- Initial modeling of support and services along tapered cones; now starting to be firmed-up with Leo Greiner.

eRD16 - Simulation Tools

- eRD16 presented an initial comparison of both concepts, e.g:



- proposed further study of this (or similar) concepts, focused on multi-particle observables; SIDIS resolutions, vertexing.
- Acceptance edges etc. starting to be studied with Winston DeGraw; clustering aspects so far deferred (tracking tool development).

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H1 Collaboration

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Accepted by Eur. Phys. J. C.

- Reduced charm cross-section and F_2 will be core measurements at the future EIC,

- Several prior studies for EIC, e.g.

  Y. Furletova et al, arXiv:1610.08536,

  E. Aschenauer et al, arXiv:1708.05654

  K-tag, D-meson invariant mass, (parametrized) vertex capability.

- Here, *initial* instrument-capability study with displaced tracks, similar to the original H1 measurement with their vertex detector.

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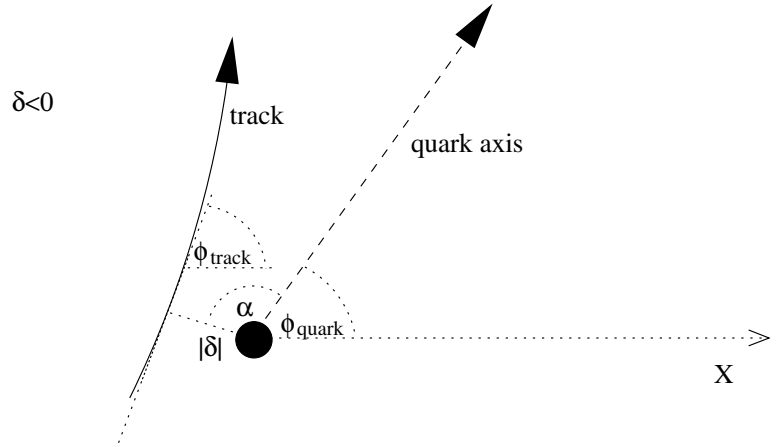

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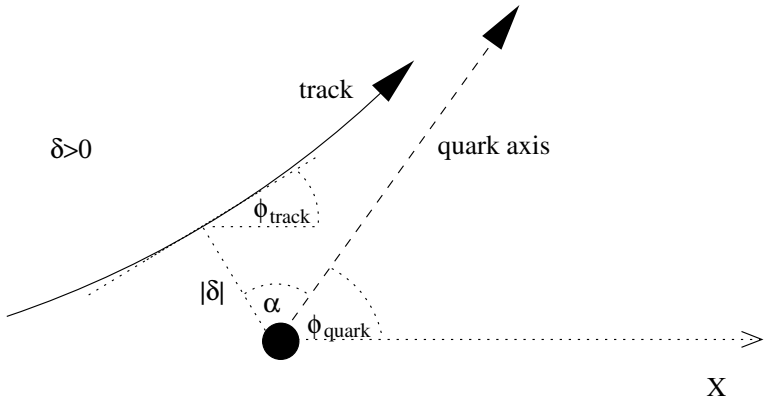

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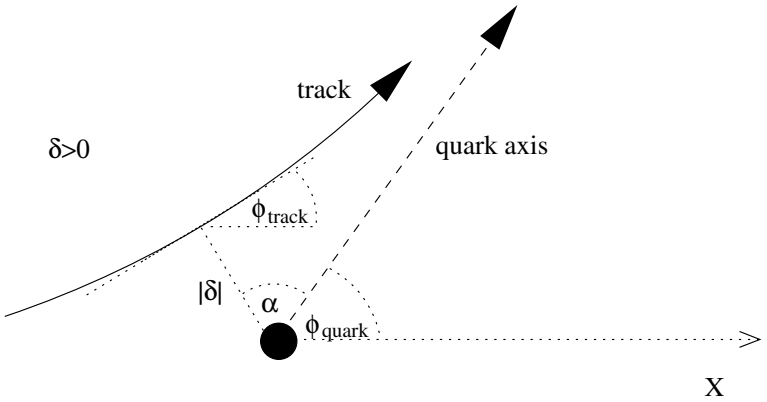

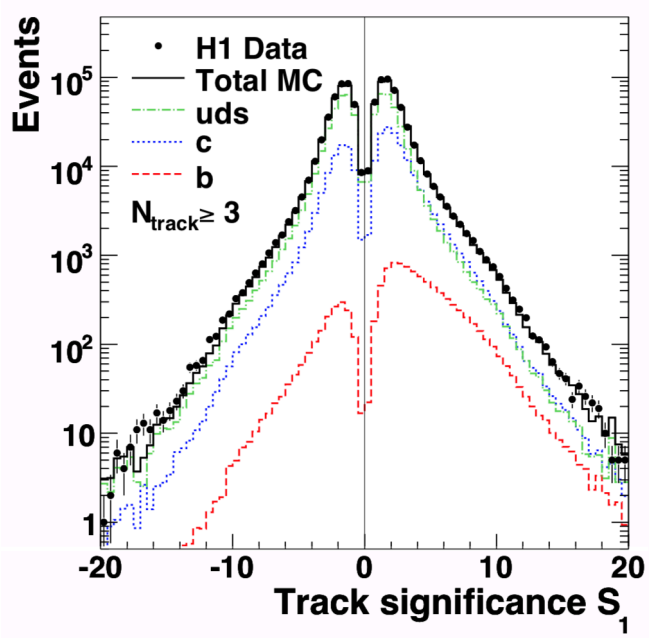

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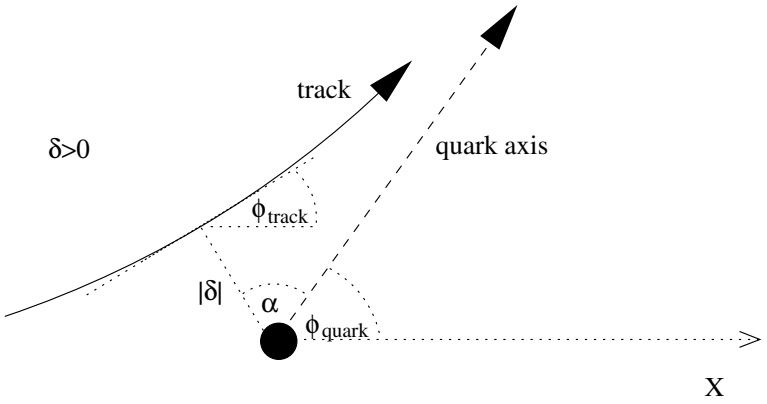

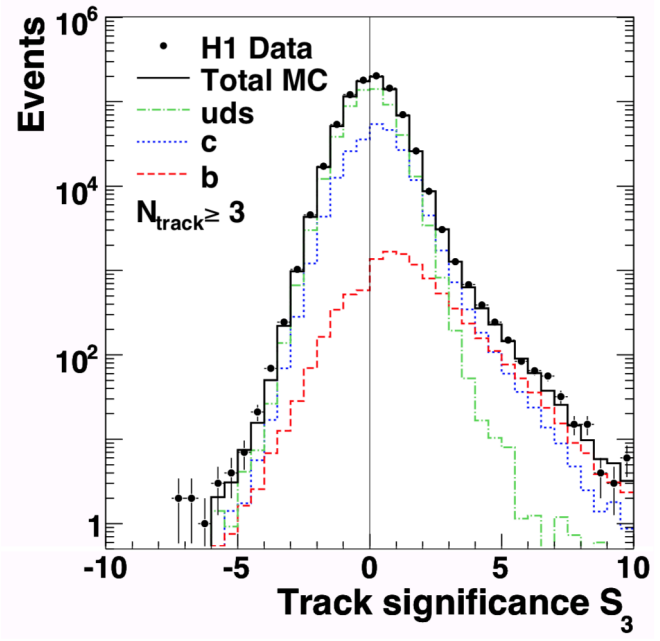

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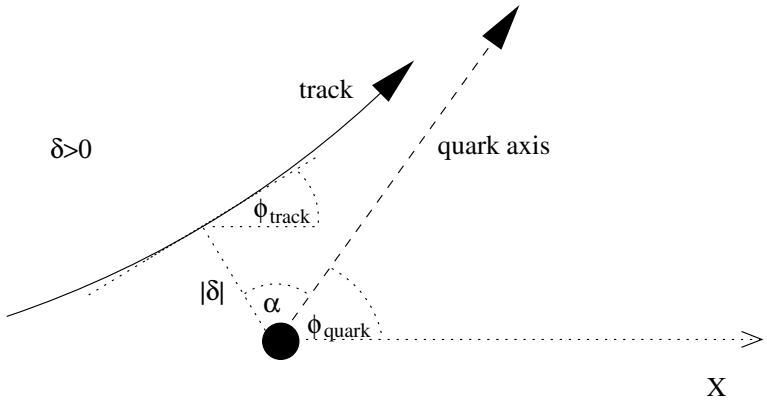

- S_1, S_2, S_3, …
- Photon-gluon fusion is an important production process at EIC; results in two “jet” events,
- Multi-particle study; combines aspects of jet-finding and vertexing.

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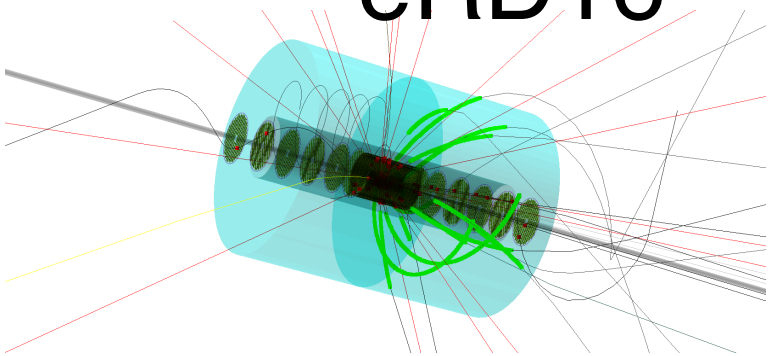
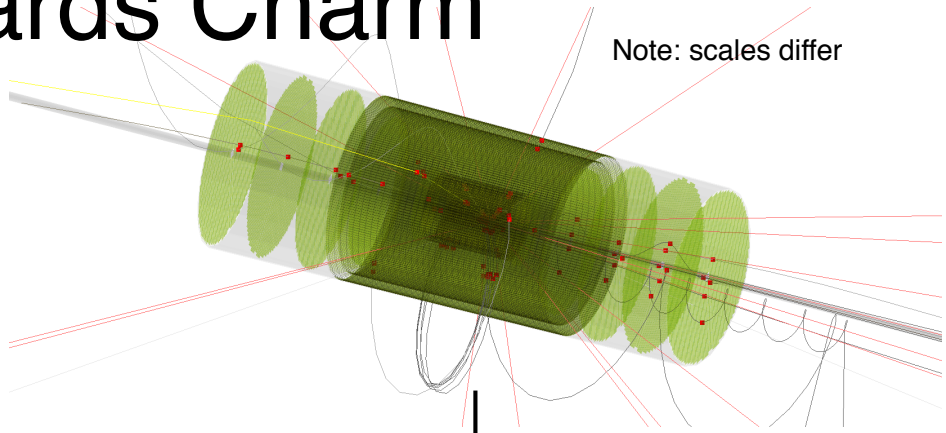
- *Initial* instrument-capability EIC study:
- 10 x 100 GeV e+p; Pythia-eRHIC,
- Instrument response from EICRoot,
- TPC+Si and all-Si concepts,
- Standalone GENFIT/RAVE event reconstruction and vertexing,
- Quark direction from scattered electron,
  - 1 particle/jet semi-inclusive DIS,

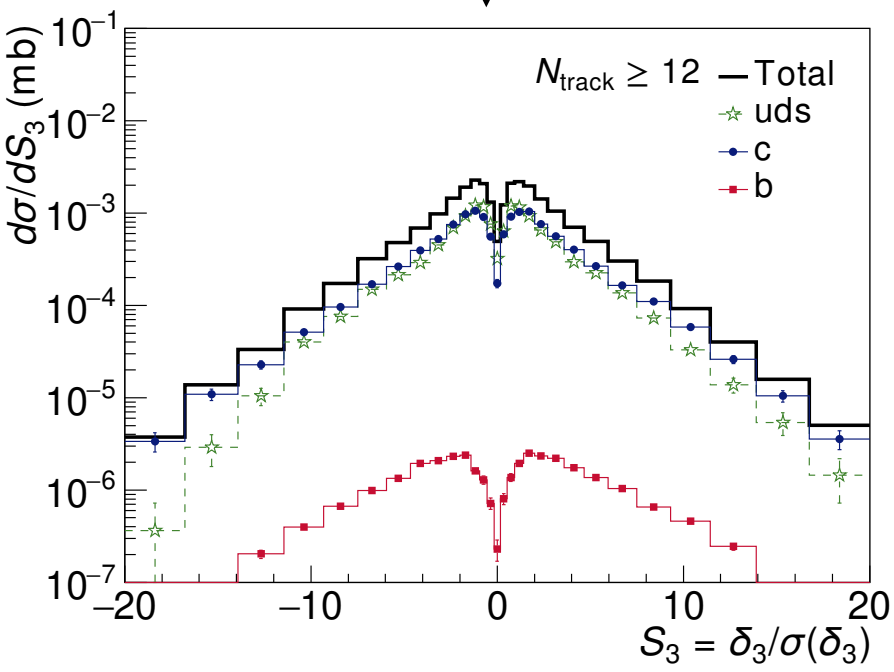
  and from FASTJET jet-reconstruction,
  - e.g. photon-gluon fusion
- Work with/by Y.S. Lai.

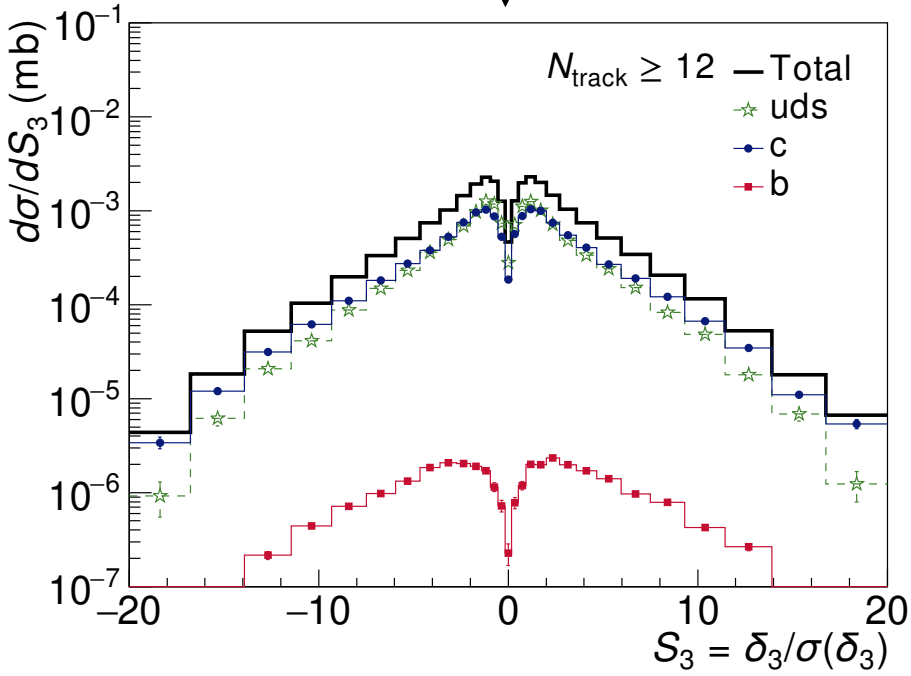
eRD16 - Towards Charm



Note: scales differ

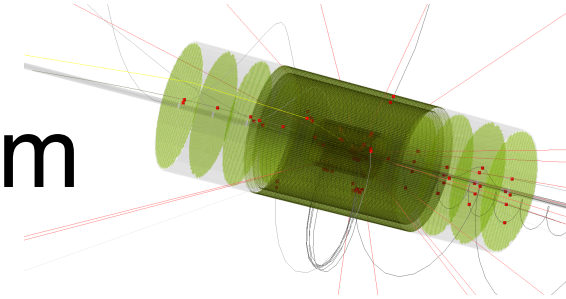




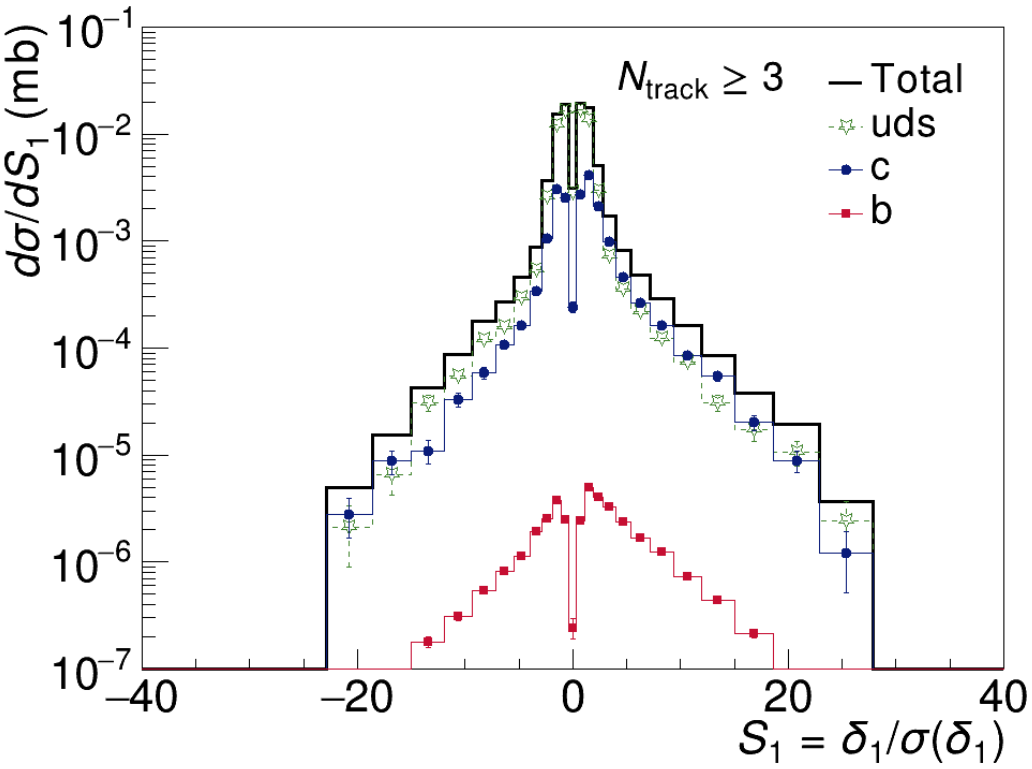


- Here, quark direction from scattered electron (i.e. limited sensitivity to photon-gluon fusion), and point-to-point distance and significance (i.e. full vertex reconstruction),
- Very similar distributions for TPC+Si and all-Si; consistent with vertex performance that is driven by the inner-most barrel layers, and overall acceptance expectations.

eRD16 - Towards Charm



20 x 20 μm pixels



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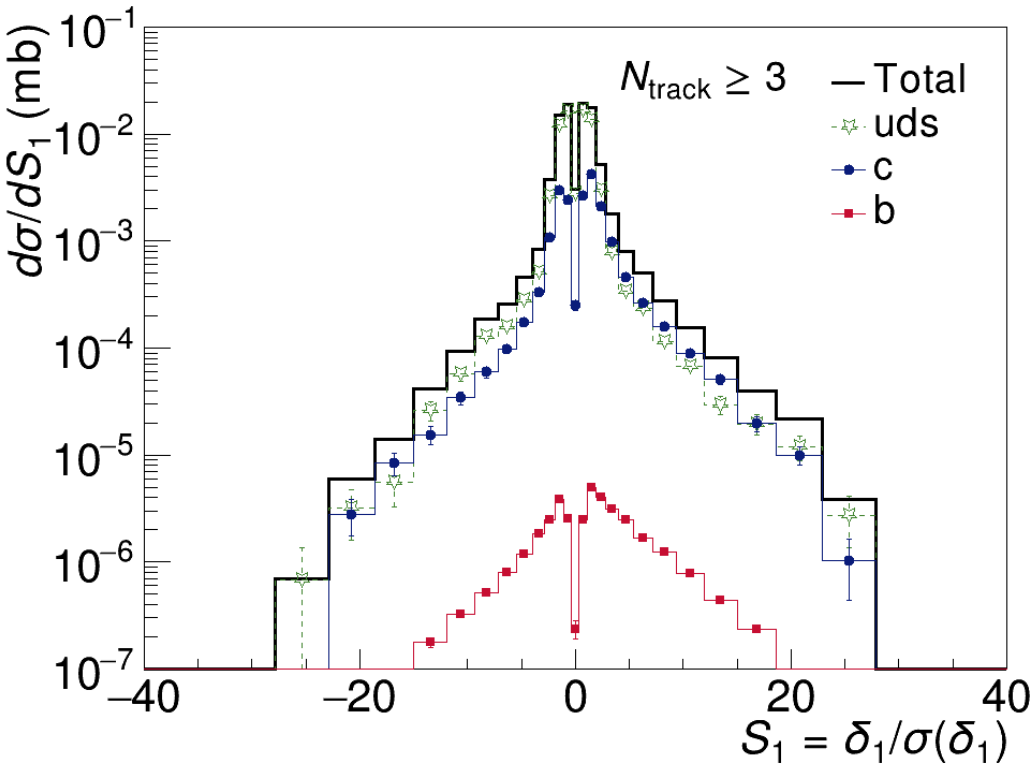
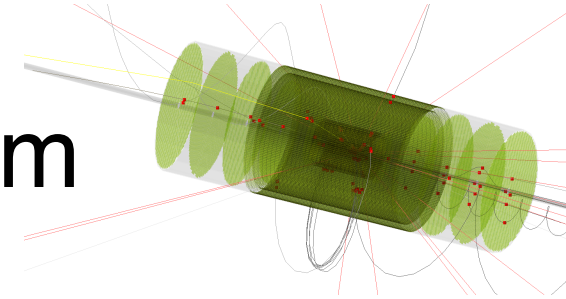


- Here, quark direction from FASTJET reconstruction; 20 μm beam-line constraint*
- Very similar, though *not* identical, distributions for all-Si concepts with 20 x 20 μm pixels and 10 x 10 μm pixels *with current material budgets.*

eRD16 - Towards Charm



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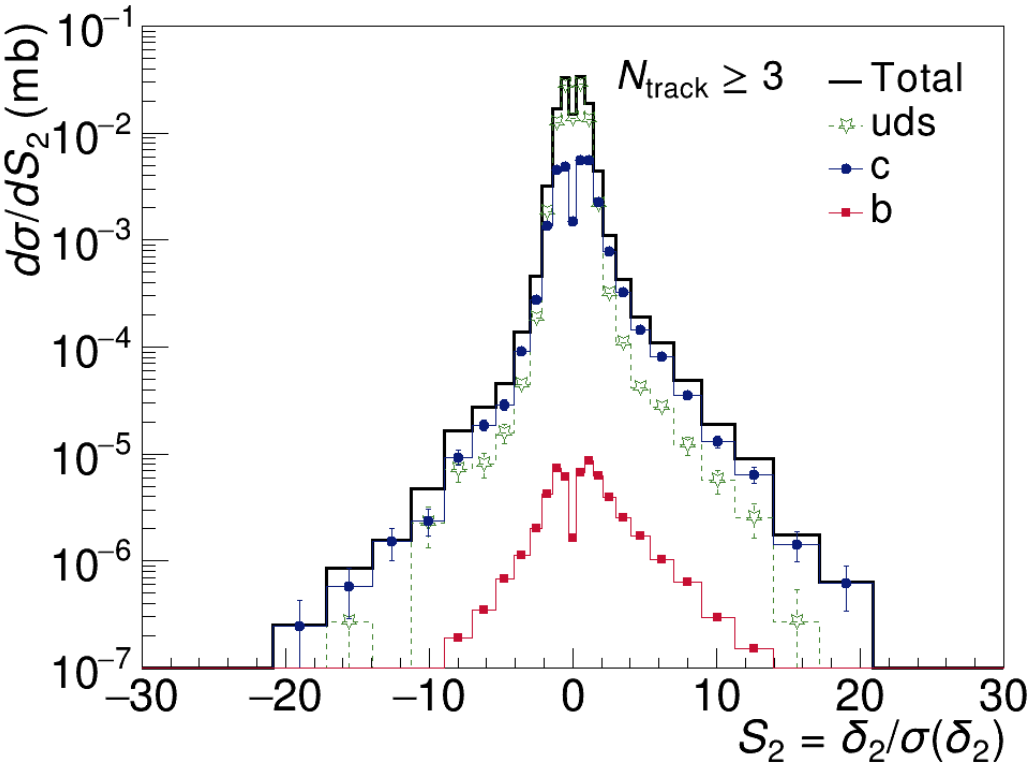

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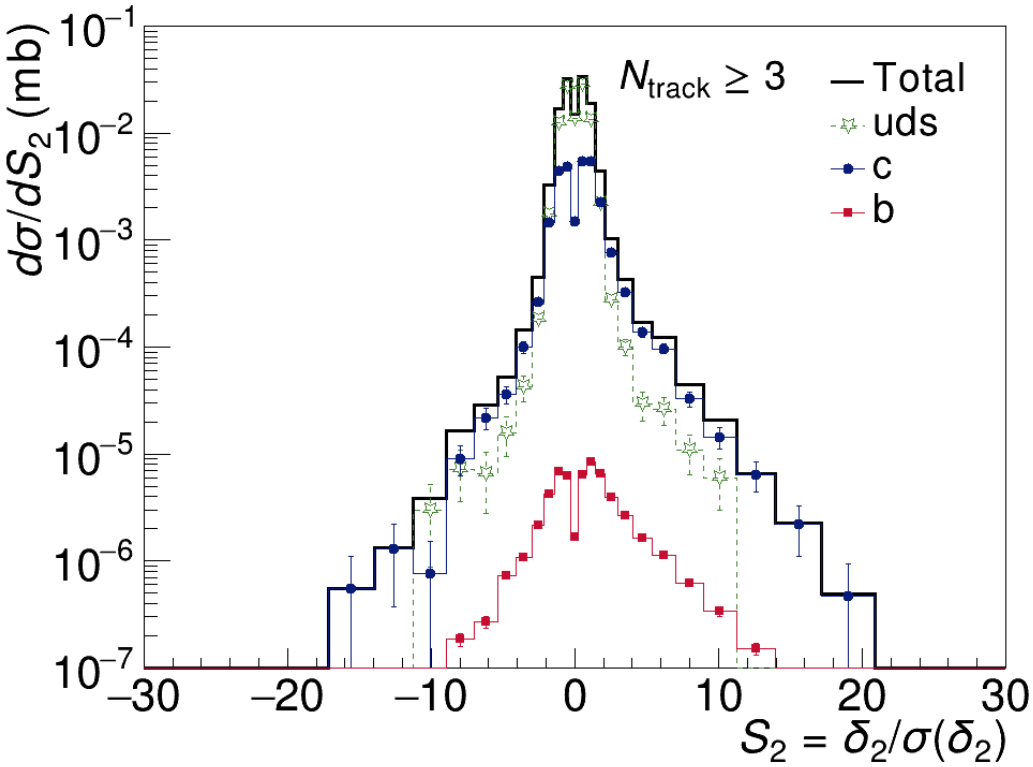

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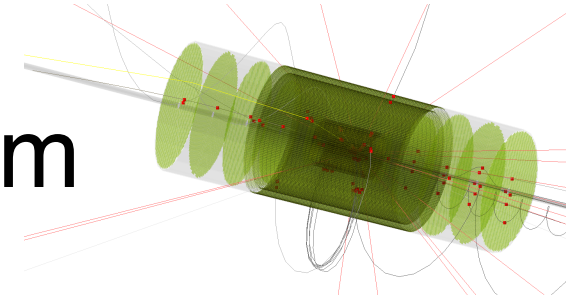

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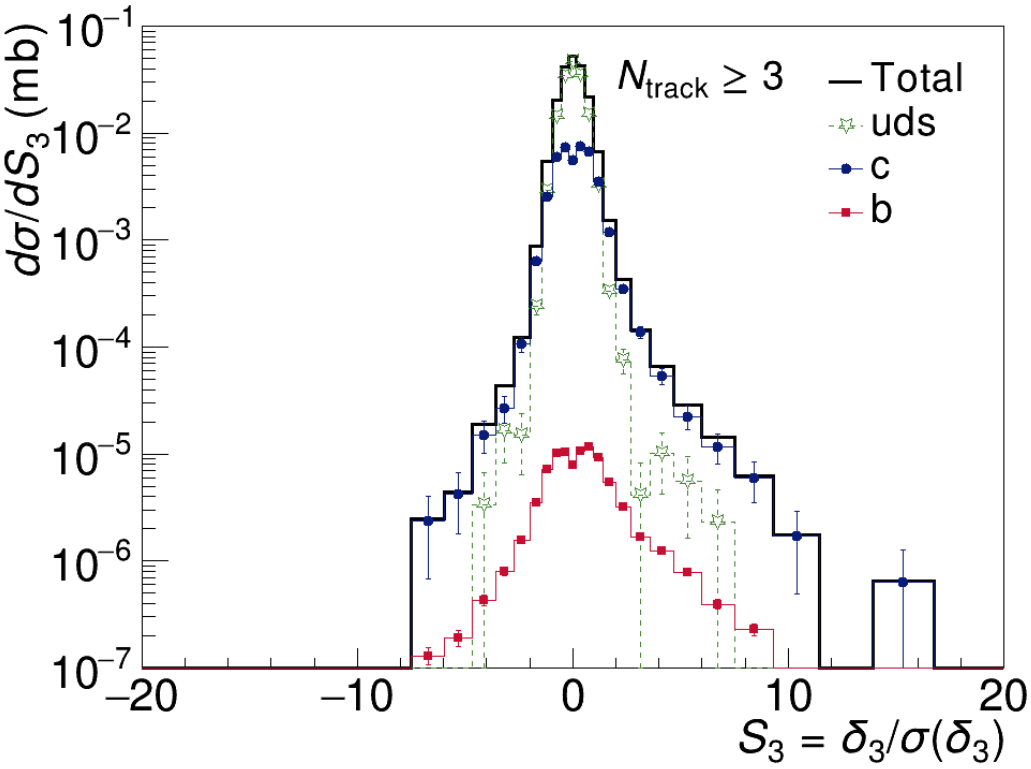
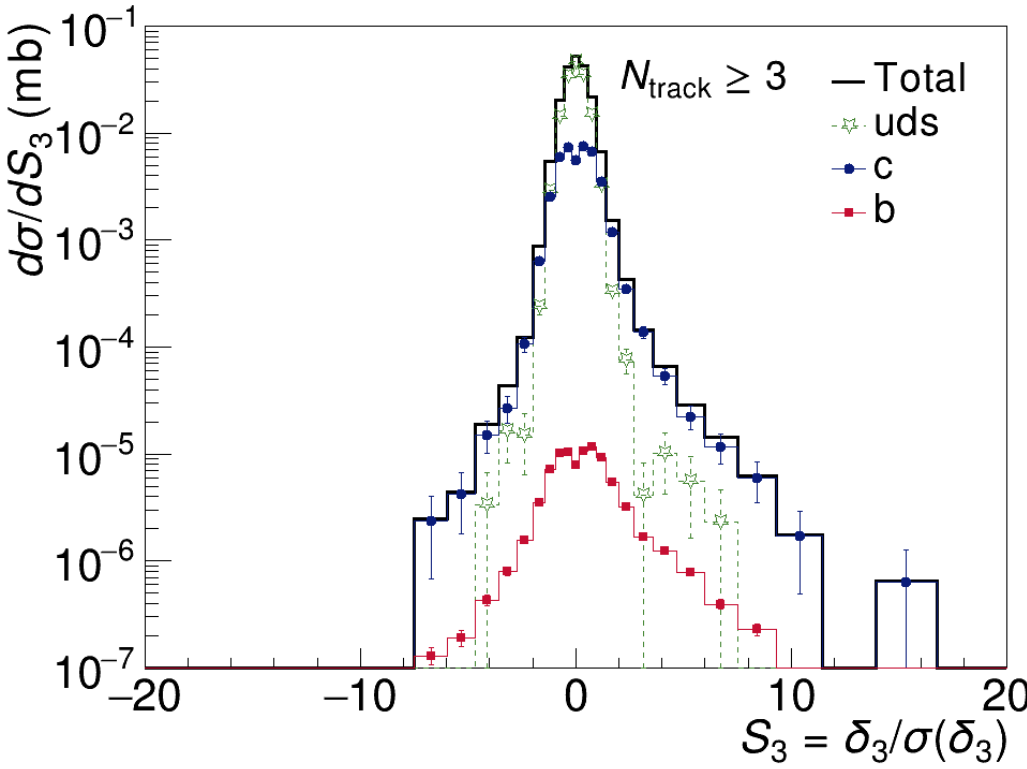


10 x 10 μm pixels



- Here, quark direction from FASTJET reconstruction; 20 μm beam-line constraint*
- Very similar, though *not* identical, distributions for all-Si concepts with 20 x 20 μm pixels and 10 x 10 μm pixels *with current material budgets.*
- Measurement capability fairly evident; bodes well (also) for full topological reconstruction.

A short presentation on

Current MAPS sensor/detector efforts at CERN
With possible application to EIC

Kickoff meeting held at CERN on December 4, 2019 for "ALICE ITS Upgrade in LS3"

https://indico.cern.ch/event/860914/

The most relevant efforts in this Letter of Intent (endorsed by the LHCC in September 2019) include:

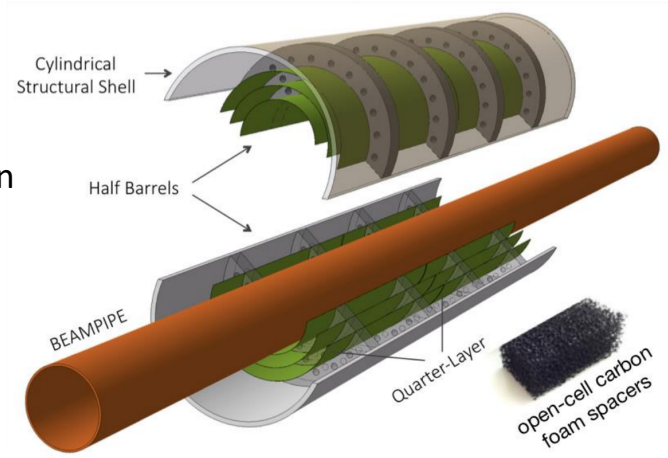
- Silicon R&D for next generation MAPS sensor (with significant improvements)

coupled with

- R&D into extremely low X/X0 cylindrical vertex detection with "bent" silicon

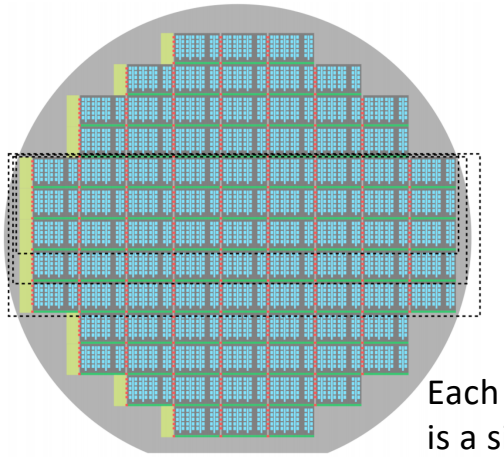
Much of this has already been presented by my colleague Vito Manzari at 2019 EIC User Group Meeting, 22-26 July 2019 Paris

"bent" silicon Detector concept



X/X0 ~ 0.05%

"stitched" silicon



Each layer half barrel is a single stitched sensor

From Electron-Ion Collider Detector Requirements and R&D Handbook Version 1.1 p.30 4.1.1.2 Vertex/silicon tracker:

"With respect to ALPIDE, the EIC would certainly benefit in improvements in the integration time as well as in a further reduction of the energy consumption and material budget going towards 0.1-0.2% radiation length per layer. Timing-wise the ultimate goal of this technology would be to time stamp the bunch crossings where the primary interaction occurred."

Sensor Specifications

Parameter	**ALPIDE (existing)**	**Wafer-scale sensor (this proposal)**
Technology node	180 nm	65 nm
Silicon thickness	50 µm	20-40 µm
Pixel size	27 x 29 µm	O(10 x 10 µm)
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	~ 5 µs	~ 200 ns
Time resolution	~ 1 µs	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm^2	100 MHz/cm^2
Max particle readout rate	10 MHz/cm^2	100 MHz/cm^2
Power Consumption	40 mW/cm^2	< 20 mW/cm^2 (pixel matrix)
Detection efficiency	> 99%	> 99%
Fake hit rate	< 10^{-7} event/pixel	< 10^{-7} event/pixel
NIEL radiation tolerance	~3 x 10^{13} 1 MeV n_{eq}/cm^2	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	3 MRad	10 MRad

Comments

- This approved and supported research and development project contains many elements that can have application in an EIC detector set.
- The overlap between the sensor development goals and EIC requirements is significant.
- The timeframe (ALICE ITS 3 installation during CERN LS3) seems to be a reasonable match.
- CERN and collaborators will invest significant resources in this project => high likelihood of success.

- LBNL-RNC has joined this effort.
- In addition to the ALICE work package efforts that we are joining, we intend to also invest in the development of making stitched sensors into low X/X0 discs.
- We have spoken to others about these efforts (ITS3 silicon/detector and discs) and there is some interest in forming a group effort for applying these developments for EIC.

- Any questions or interest, please talk to me.

eRD16 - Closing Comments

Simulations have moved beyond basic single-track quantities; vertexing well underway, 1-particle SIDIS limited by staff availability thus far.

eRD16 engaging in “Yellow Report”; studies, co-conveners of subgroups,
Simulations are never done, but anticipate to ~transition into YR effort,

Looking forward, eRD16 and eRD18 consider it ~now timely to form a consortium, open to new other collaborators,

Several University of California (-related) colleagues made a proposal to 2019 U.C. Multi-campus Research Funding Opportunity. This was awarded, P.I. B. Jacak. This will enable a small number of students at collaborating U.C. campuses to engage in EIC research. U.C. Davis student is starting to engage in eRD16-related effort. (Re-)engagement from U.C. Berkeley students as well.

eRD16 - Mandatory Slide

How much time do you envision to complete your ongoing project(s)?

- Simulations are stopped, never competed. Anticipate that most simulation effort will take place in the context of the 12-18 month “Yellow Report” effort that has just started,

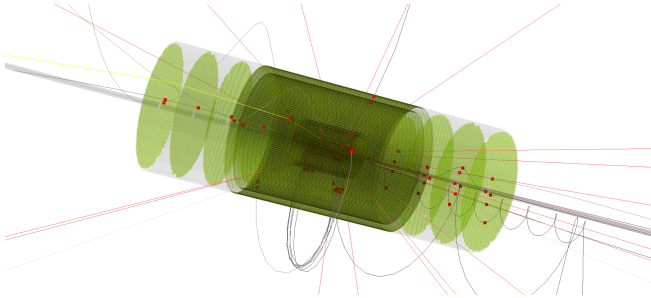
- Instrumentation effort will naturally adopt/adapt to ALICE ITS3 time-lines, which have yearly milestones into Q4 2023 (consistent with EIC timelines).

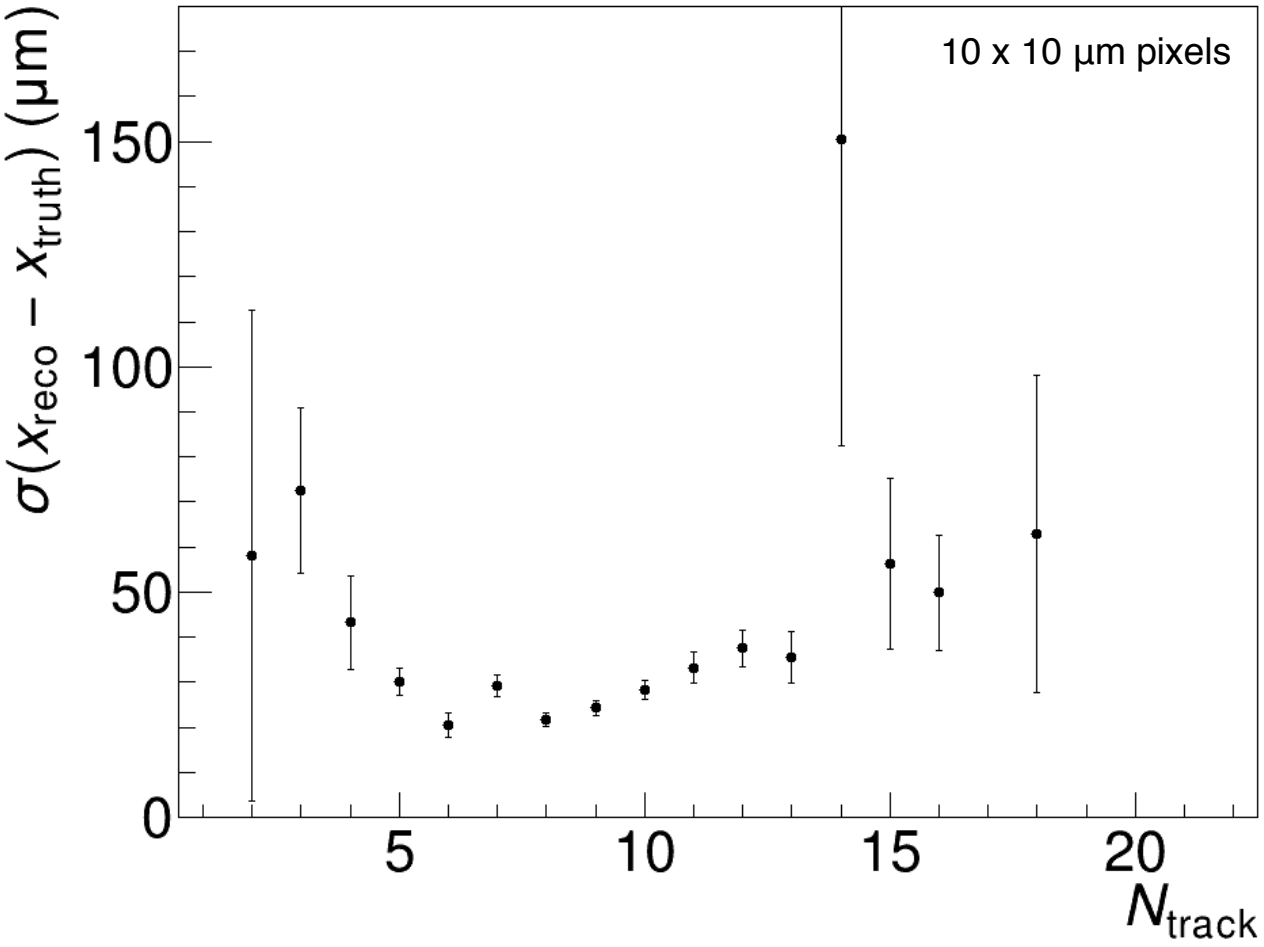
What achievements are required for TDR readiness in 2023?

- Now started “Yellow Report” effort needs to succeed, on time ⟶ CDR.

- Sensor and necessary infrastructure understood on EIC and ALICE ITS3 timeline (presumed to remain consistent), mechanical design sufficiently developed.

Backup




10 x 10 µm pixels
σ(x_reco − x_truth) (µm)
150
100
50
0
5
10
15
20
N_track